5. INSTRUMENT OPERATIONS

The TRMM observatory is comprised of 5 instruments: Precipitation Radar (PR), Visible and Infrared Scanner (VIRS), TRMM Microwave Imager (TMI), Clouds and Earth's Radiant Energy System (CERES), and Lightning Imaging Sensor (LIS). The PR, VIRS, and TMI instruments are the primary instruments and form the rain package. The mission is based on the success of these three instruments. The FOT in the MOC will operate all 5 instruments. However, VIRS and TMI will be the responsibility of the SOCC, while EOC is responsible for PR. The additional instruments, CERES and LIS, will complement the rain package and will be operated by the FOT under the direction of LaRC and MSFC respectively. Figure 5-1 depicts the instruments and their locations on the TRMM spacecraft.

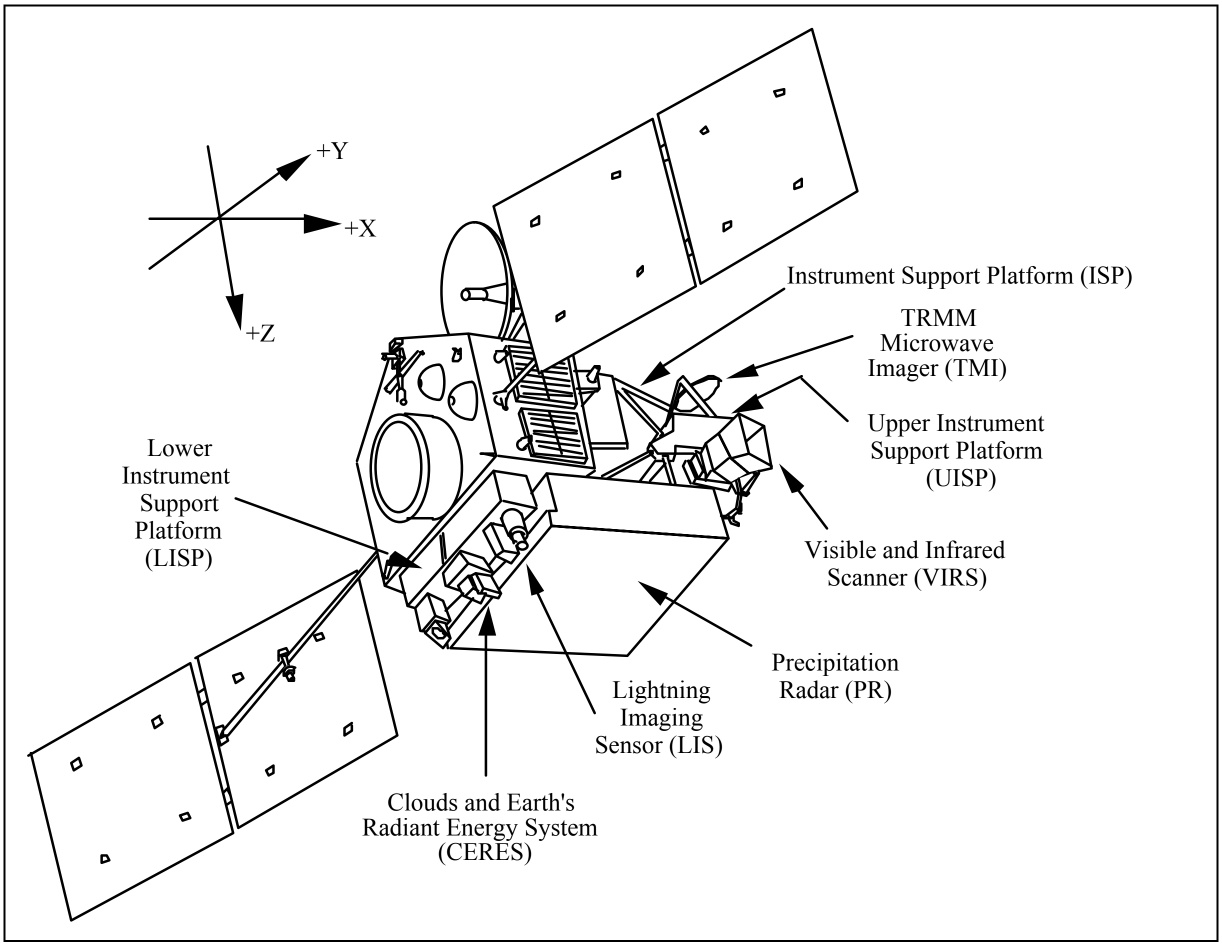

Figure 5-1 TRMM Instruments

The majority of instrument operations are nominally contained in the daily spacecraft command load, which is generated by the TRMM Mission Planning & Scheduling Analyst. Typical instrument activities include reconfiguration based on orbital conditions (eclipse entry/exit), spacecraft configuration (180° yaw maneuver) changes, changes to instrument scan modes, and instrument calibrations. Requests for commanding will come from the SOCC for PR (via EOC), VIRS, and TMI. CERES and LIS requests will come directly from their respective instrument scientists.

The FOT will monitor the general health and safety of all instruments during real-time supports. The Instrument Scientists will be responsible for overall health and safety of the instruments. In the event of an anomaly, the FOT will notify the respective facilities as shown in Table 5-1. Contingency response procedures, resident in the MOC, will contain responses to certain anomalous conditions for all the instruments. These will include out of limits conditions for power, temperature, and other telemetry points. If this type of an anomaly occurs, the FOT will send necessary commands via pre-approved STOL procedures to take corrective action. In the case of a severe anomaly (one in which there was not a previously defined response), the FOT will aide the instrumenters in anomaly investigation and will await further instructions from the instrument personnel upon final resolution. Any instrument commanding, in addition to an anomaly report, will be reported to the respective instrument sites.

INSTRUMENT	RESPONSIBLE FACILITY	SCIENCE DATA RATE	HOUSEKEEPING DATA RATE
PR	EOC/TSDIS SOCC	93 Kbps	1 Kbps
VIRS	INSTRUMENT SCIENTIST via TSDIS SOCC	49.84 Kbps - Day 28.83 Kbps - Night	1 Kbps
TMI	INSTRUMENT SCIENTIST via TSDIS SOCC	8.5 Kbps	300 bps
CERES	LaRC	8.5 Kbps	300 bps
LIS	MSFC	8 Kbps	500 bps

Table 5-1 Instrument Information

5.1 PRECIPITATION RADAR

The PR is the primary instrument on the TRMM observatory. It is the first instrument of its kind to be flown in space. The PR is an active radar instrument that will continuously measure rain rate over land and ocean during both daytime and nighttime periods. The PR data, along with data from TMI, will aid in understanding the world-wide rainfall distribution of tropical and sub-tropical regions, thus increasing our understanding of the properties of rainfall in these regions. The PR is attached to the Instrument Support Platform (ISP) on the +Z side of the spacecraft, as shown in Figure 5-1. The PR instrument is shown in Figure 5.1-1.

The PR measures the intensity of the rain over a frequency of 13.8 GHz, using two-channel frequency agility. Its vertical and horizontal resolutions are 250 m and 4.3 km at nadir, respectively, over a swath width of 215 km. The instrument consists of a 128-element waveguide planar array, which has a beamwidth of 0.71° X 0.71°. Electrical beam scanning is performed using the 5 bits digital phase shifter. PR requires that the geodetic altitude of the TRMM observatory shall be kept within the range of +7/-8 km. The Project Mission Specification states a requirement to maintain the mean orbit semi-major axis within ±1.25 km of 350 km plus the Earth equatorial radius. Maintaining the TRMM spacecraft in a near-circular frozen orbit with the semi-major axis will accomplish the PR requirements. The PR instrument can operate in 7 different modes, which are described in Table 5.1-1. Nominal operations will take place while the instrument is in Observation mode.

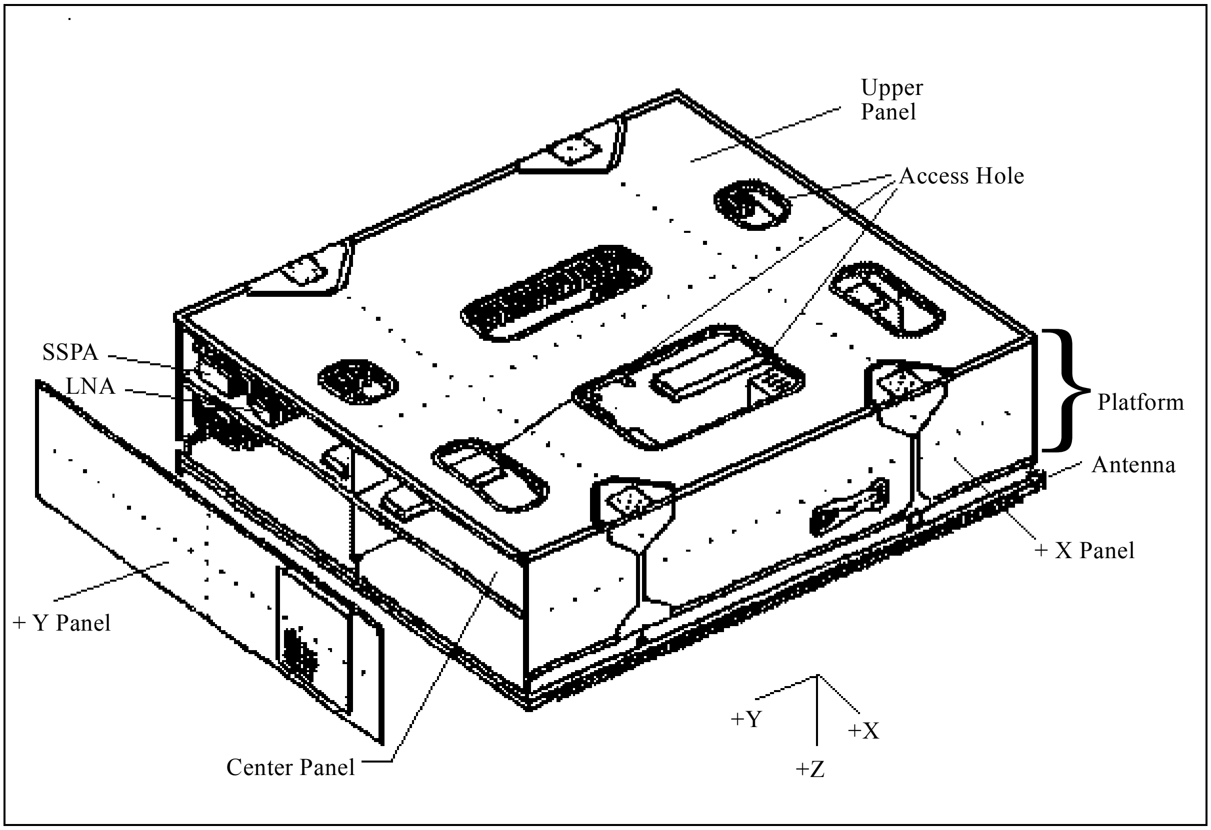

Figure 5.1-1 Precipitation Radar

5.1.1 PR Normal Operations

The PR instrument requires little day to day commanding. Generally, external and internal calibrations will be performed approximately once a month. Nominally, the external calibration will be performed in the limited scan mode, which will use 7 of the 103 beams and disregard the remaining. The calibration must be performed when TRMM passes over an ARC located in Japan. The NASDA/EOC will define the time and the center beam number at which this calibration must be performed. An internal calibration will be performed in conjunction with the external calibration.

The Antenna Pattern Measurement consists of two types of external calibrations; a cross track antenna pattern and an along track antenna pattern. An Antenna Pattern Measurement containing the crosstrack configuration will be performed approximately every 6 months, over a specified position containing an ARC. NASDA/EOC will provide times and a beam number to the FOT, via TSDIS SOCC. The Cross-track Antenna Pattern Measurement will require a 90° yaw maneuver of the spacecraft to point the -Y axis towards the velocity vector. The maneuver will take approximately 15 minutes (maneuver and settling time). The calibration itself should only take approximately 5 minutes, at which time the spacecraft will be yawed back to its nominal orientation (±X forward). Before the Cross-track Antenna Pattern Measurement is initiated, the

PR will be commanded to the external calibration, fixed beam mode, in which a beam number is also commanded to the instrument. The beam number will correspond to a specific angle which NASDA EOC will use to point the ARC. The Cross-track Antenna Pattern Measurement Calibration timeline is shown in Figure 5.1-2.

PR MODE	MODE DESCRIPTION
All OFF	The PR instrument will be powered OFF, with survival heater power OFF, and in its safe configuration. The all-off mode will only be used on the ground.
Observation	This will be the normal operating mode of the instrument. During this mode, the PR instrument performs normal rain echo measurements with a $\pm 17°$ scanning range. System noise, surface return, and mirror image data are also collected.
External Calibration	This mode will provide an on-orbit calibration of the PR instrument by the Active Radar Calibrator (ARC) on the ground. Limited scan or Fixed beam submodes may be used in either the spacecraft nominal configuration or the 90° yaw configuration. Limited scan - scanning for 7 beam directions centered at a selected angle bin. Fixed beam - Beam is fixed to a selected angle bin. No scanning is performed.
Internal Calibration	This mode will provide an on-orbit calibration for the interpolation of the external calibration results. During this mode, no RF signal is radiated from the antenna and science observation will not occur.
Health Check	This mode is for checking RAMs and ROMs used in the System Control Data Processing (SCDP) component. By electrical power turn-on, PR moves from Safety Mode to this mode.
Analysis	This mode is used to check whether each Low Noise Amplifier (LNA) is alive or not. During this mode, no science observation will occur. This mode will be used during initial instrument checkout and may be used while the TRMM observatory is in the Mission Mode.
Stand-By	This mode is for checking the phase code stored in the SCDP. Also, this mode shall be selected to temporarily stop the RF radiation. During this mode, the PR instrument is ON but is not initiating any RF transmissions.
Safety	This mode will be used when the TRMM observatory is in either of the following modes of operation: • Launch Mode • Initial Orbit Acquisition Mode • Safe-Hold/Low Power Mode When Safe-hold/Low Power signal is received, the PR instrument will be internally commanded to this mode, prior to the autonomous removal of the NEB power supply. During this mode, the PR instrument is OFF with the exception of the survival heaters.

Table 5.1-1 PR Operational Modes

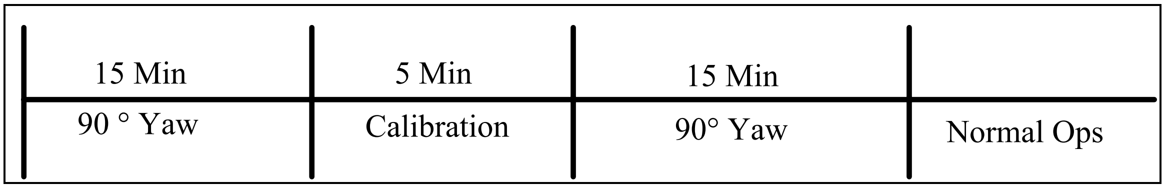

Figure 5.1-2 Antenna Pattern Measurement Calibration Timeline

Due to the restriction of keeping the Sun off of the +Y axis, the 90° yaw maneuver and crosstrack Antenna Pattern Measurement must be performed after eclipse entrance but prior to orbit noon. This time frame relates to midnight to 8 am Japan time.

Before the Along-track Antenna Pattern Measurement is initiated, the PR will be commanded to the external calibration, limited scan mode, in which the center beam number will also be commanded. The beam number will correspond to a specific angle which NASDA EOC will use to point the ARC. Along-track Antenna Pattern Measurements will be performed in the spacecraft's nominal attitude and will occur every 2 weeks to 1 month.

For LNA performance check, PR needs to enter the Analysis mode for more than 2 minutes while TRMM ground track is over the ocean. This will be required approximately every 6 months.

PR has a receiving gain control capability by using the "RX ATT select" command. This command will be executed after NASDA detects, via off-line monitoring, the degradation of PR receiving gain. Frequency of this activity is assumed to be no more than once per year.

Normal operations for the PR instrument will consist of daily health and safety monitoring of housekeeping parameters during real-time operations performed by the FOT. Routine commanding of the instrument, when necessary, will be included in the spacecraft SCP daily command load. Planning aids will be utilized by the NASDA/EOC to determine specific times of calibrations. Those times will be communicated to the FOT, via the SOCC, in order to incorporate calibration commands into that day's spacecraft command load. A PR operational modes flow diagram is shown in Figure 5.1-3.

5.1.2 PR Special Operations

The PR instrument design includes 128 Phase Shifters, each with 206 settings. The Phase Shifter settings are loaded into the PR instrument RAM in the SCDP component. Basically, these settings are not expected to change during the course of the mission. However, since they are loaded into RAM, they must be reloaded after each interruption to PR power (i.e., Safe-Hold, Low Power, etc...). The phase shifter settings will be sent to the OST from the NASDA/EOC via the TSDIS SOCC. The OST will create a STOL procedure with which the FOT will execute the 206 commands for transmission and receiving angle bins and verify the phase shifter settings via a NASDA/EOC provided checksum value. When severe degradation of the antenna pattern is observed, NASDA/EOC may update the phase code to improve the performance.

The PR instrument will be commanded to the Standby mode, and the load will be uplinked. After load completion, the PR instrument will provide a computed checksum (downlinked in the PR housekeeping packet). The downlinked checksum will be autonomously compared to the ground computed checksum contained in the STOL Procedure. If the checksum is verified, the PR instrument will be commanded to the Observation mode (normal mode), or else PR will remain in the Standby mode. Normally, PR RAM for phase code will not require a memory dump upon successful uplink of a Phase Shifter load. If for some reason the FOT would be requested to dump the phase code stored, NASDA/EOC will receive the dump packets via a Quicklook from Pacor.

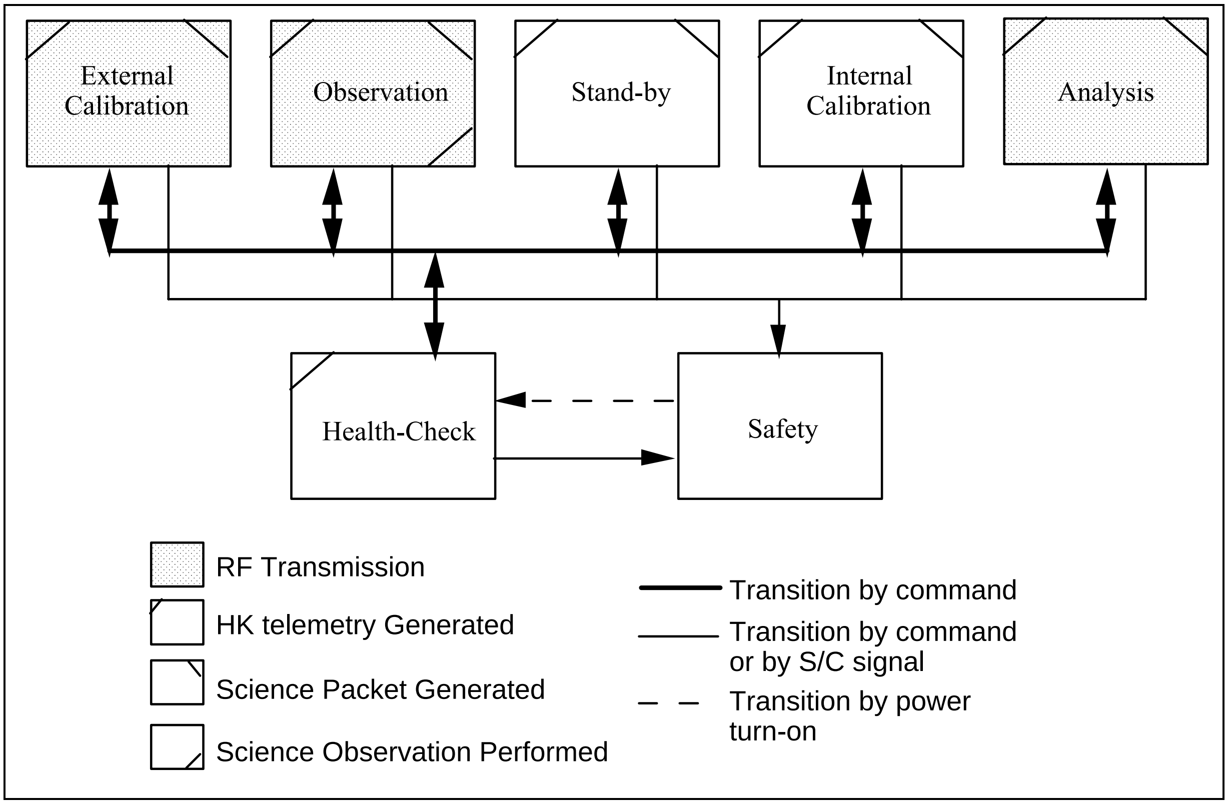

Figure 5.1-3 PR Operational Modes Flow

Approximately every 6 months, PR will be commanded to Analysis mode. This transition will be used to check the health of the LNAs. In addition, approximately once per year gain control commands will be sent to the PR instrument to adjust the gain.

During initial instrument checkout, the CERES instrument will perform a Deep Space Calibration for at least one orbit. This calibration will require the spacecraft to be configured in an inertially fixed attitude. During this time, PR will be placed in Standby Mode so as not to radiate into deep space. Delta-V and yaw maneuvers will not require PR to perform any special operations.

If an anomaly is detected in either the SCDP or FCIF, A/B switching will be required. Basically, the FCIF will use the same side as the working SCDP. In special cases, cross connection (FCIF A and SCDP B) will be possible.

When a Safehold or Low Power condition occurs on the spacecraft, the IPSDU will issue a pulse, notifying the instruments that power provided by the Non-Essential Bus will be removed in 90 seconds. When PR receives this pulse, it will transition to the Safety Mode at which time it will turn itself OFF. Ninety seconds after receiving the pulse, the relay that provides Non-Essential bus power to the PR instrument will be commanded open and power will be removed from the instrument. Thermostatically controlled survival heaters will remain powered for thermal control of the instrument. When the relay is closed again, essentially providing Non-Essential bus power back to PR, the SCDP will be powered on and will initialize its CPU. This initialization takes about 5 seconds. During this period, PR will not accept the SH/LP signal. Even if the relay is opened in this condition, PR will not receive any damage.

5.1.3 NASA/NASDA Interface

NASA/NASDA detailed data interface regarding operation information shall be defined in the Operation and Interface Specification (OIS), TRMM-490-042.

5.2 VISIBLE AND INFRARED SCANNER

The VIRS instrument is a cross-track scanning radiometer which measures scene radiance in five spectral bands operating in the visible through the infrared spectral regions. The VIRS is similar to instruments flown on NASA and NOAA meteorological satellites, but was specifically designed for the TRMM orbit and scientific requirements. It will serve as a background imager and will provide the cloud context within which the passive microwave and radar observations are made. Data from the VIRS instrument will be used in rain estimation algorithms based primarily on the passive and active microwave sensors. Comparison of the visible and infrared data with microwave data is expected to provide the means whereby precipitation will be estimated more accurately than by visible and infrared data alone. Figure 5.2-1 depicts the VIRS instrument and its components.

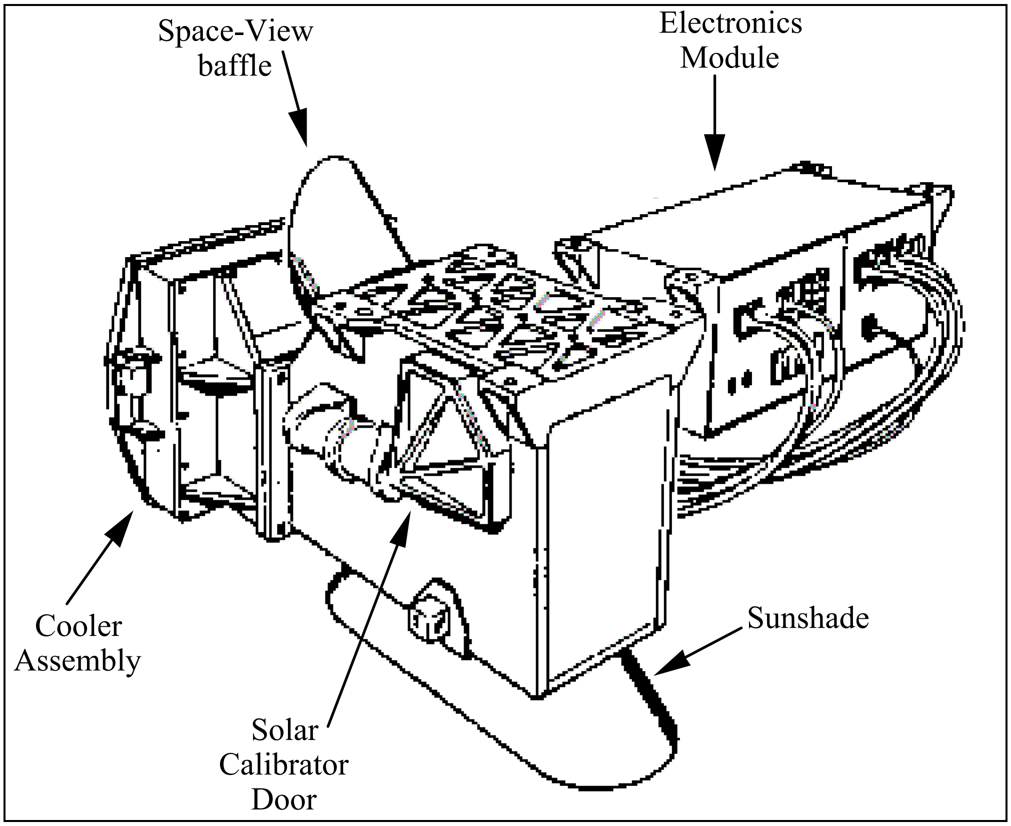

Figure 5.2-1 VIRS Instrument

The VIRS instrument measures scene radiance in five spectral bands; 0.63, 1.61, 3.75, 10.80, and 12.00 µm. The characteristics of each band are depicted in Table 5.2-1.

The scan system consists of a paddle wheel scanner which includes a continuously rotating, double-sided scan mirror. The scan mirror rotates through key positions, including a blackbody source, a space view, a solar view, and a nadir view (Earth scan). Each synchronous scan cycle is based on an encoder home index reference which is scanned each revolution. The scan cycle is shown in Figure 5.2-2.

Channel	Wavelength (µm)	Spectral Range
1	0.63	Visible
2	1.61	Infrared
3	3.75	Middle Wave Infrared
4	10.80	Long Wave Infrared
5	12.00	Long Wave Infrared

Table 5.2-1 VIRS Channel Characteristics

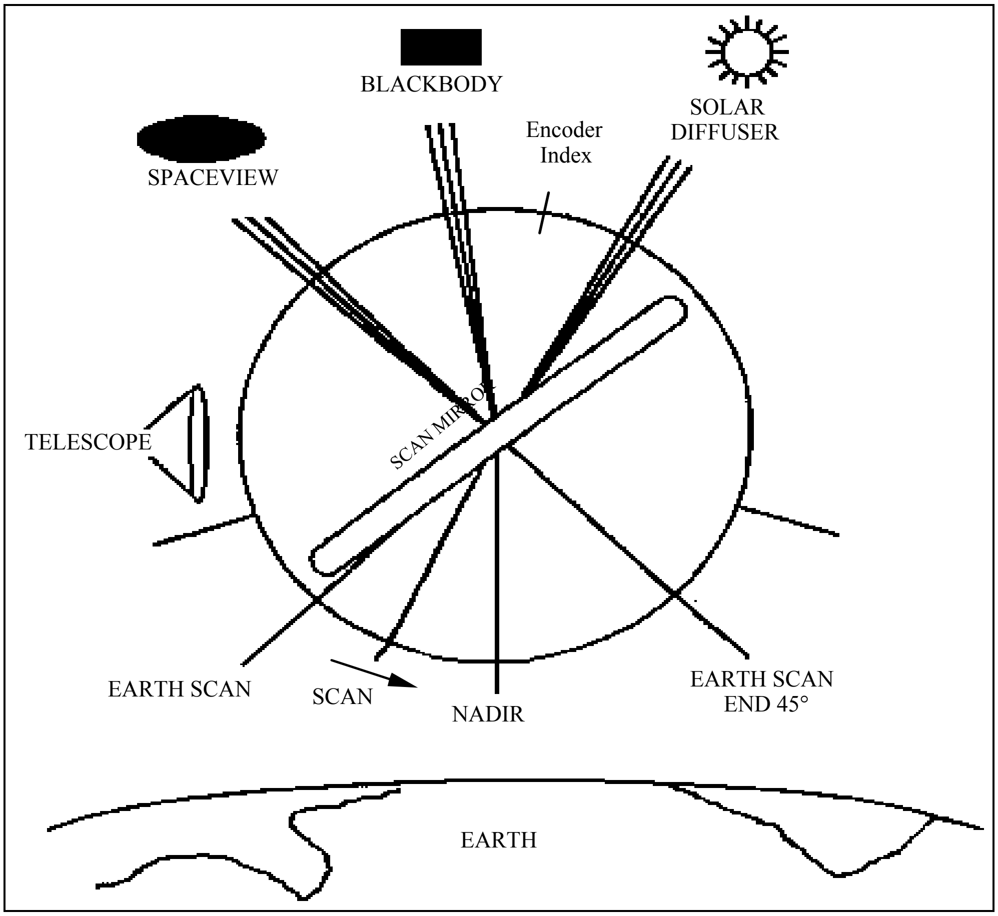

Figure 5.2-2 VIRS Scan Cycle

VIRS has the capability of operating in 5 different modes. The mode types and their descriptions are found in Table 5.2-2. Within the VIRS mission mode, two submodes, Day mode and Night mode, will be used daily for normal operations. VIRS will operate in the Day mode during sunlit portions of the orbit and in the Night mode during eclipse periods. In Day mode, all 5 channels are sampled for data each scan. In Night Mode, data from channels 1 and 2, which consist of reflected solar radiation, are not read during the night portions of the orbit. By eliminating channels 1 and 2 each orbit for approximately 20 minutes (a portion of the eclipse period), the average orbital data rate will decrease, which will aid in freeing valuable space on the solid state recorders.

Operational Mode	Description
Off	VIRS is unpowered by the TRMM spacecraft
Activation	VIRS is powered by the TRMM spacecraft but the VIRS scanning system is OFF
Mission	Normal data collection mode with the VIRS scanning system ON
Outgas	Mode used to decontaminate the radiative cooler

Safehold	Protected OFF mode in which all doors are closed and the shutter is obscuring the optical path

Table 5.2-2 VIRS Mode Description

The VIRS instrument possesses a radiative cooler, which includes a Solar Panel Shield and an Earth Panel shield. The Solar Panel Shield will prevent the Sun from shining into the VIRS cooler and the Earth Panel Shield will be deployed to block the Earth's reflected Sunlight. The Solar Panel Shield is opened by actuating a “one time only” paraffin latch. The Earth Panel Shield will also act as the Cooler door during times of safehold and outgassing.

A solar calibrator door is located on the +X side of the VIRS instrument. This door will be commanded open during solar calibrations to allow the Sun to shine on the solar diffuser and into the telescope to the focal plane. The door will be commanded closed after the calibration period has expired.

The VIRS instrument is also equipped with a Safehold shutter. The shutter is used during the Safehold/Low Power modes when power is removed from the VIRS instrument. The shutter is controlled by a Daco rotary solenoid. The shutter can also be opened by turning off the VIRS switched essential shutter power. A backup mechanism to force the shutter open via ground command is also available.

5.2.1 VIRS Normal Operations

Commanding of the VIRS instrument will normally be minimal. Switching VIRS from the Day mode to the Night mode will be accomplished by the spacecraft telemetry and statistics monitoring (TSM) capability. The spacecraft processor will monitor for day/night conditions using the PSIB "time of day" telemetry. The TSM will monitor for night conditions and then trigger an RTS. The RTS will wait 3 minutes, command VIRS to Night mode, wait 20 minutes, then command VIRS back to Day Mode. This will occur every orbit.

Solar calibrations will be performed approximately every 1 - 3 weeks, when the Sun is in the field of view of the solar calibrator door. Planning aids will be utilized by the VIRS Instrument Scientist to determine specific times of the calibration. Those times will be communicated via the SOCC to the FOT for the inclusion of calibration commands into the daily spacecraft command load. Two commands will be necessary for the VIRS solar calibration, a calibration door open and a calibration door close command.

A 180° yaw maneuver will be performed every two to four weeks when the Sun reaches a Beta angle of 0° in order to keep the Sun off the +Y side of spacecraft. The maneuver will be performed in darkness (during eclipse) to avoid the possibility of the Sun shining on VIRS. Details of ACS operations during yaw maneuvers can be found in section 4.2 and of the yaw maneuver planning process in section 7.1.

Normal operations for the VIRS instrument will consist of general health and safety monitoring of instrument housekeeping data during real-time operations. Thermal monitoring of VIRS will also be included. VIRS contains operational heaters which can provide 4 discrete amounts of heater power to the VIRS scanner to maintain its temperature within a 0° to 20° C range. The operational heaters are commandable via the 1773 command link. Limits will be set and monitored on the ground during real-time events. Figure 5-2.3 shows the operational temperature ranges.

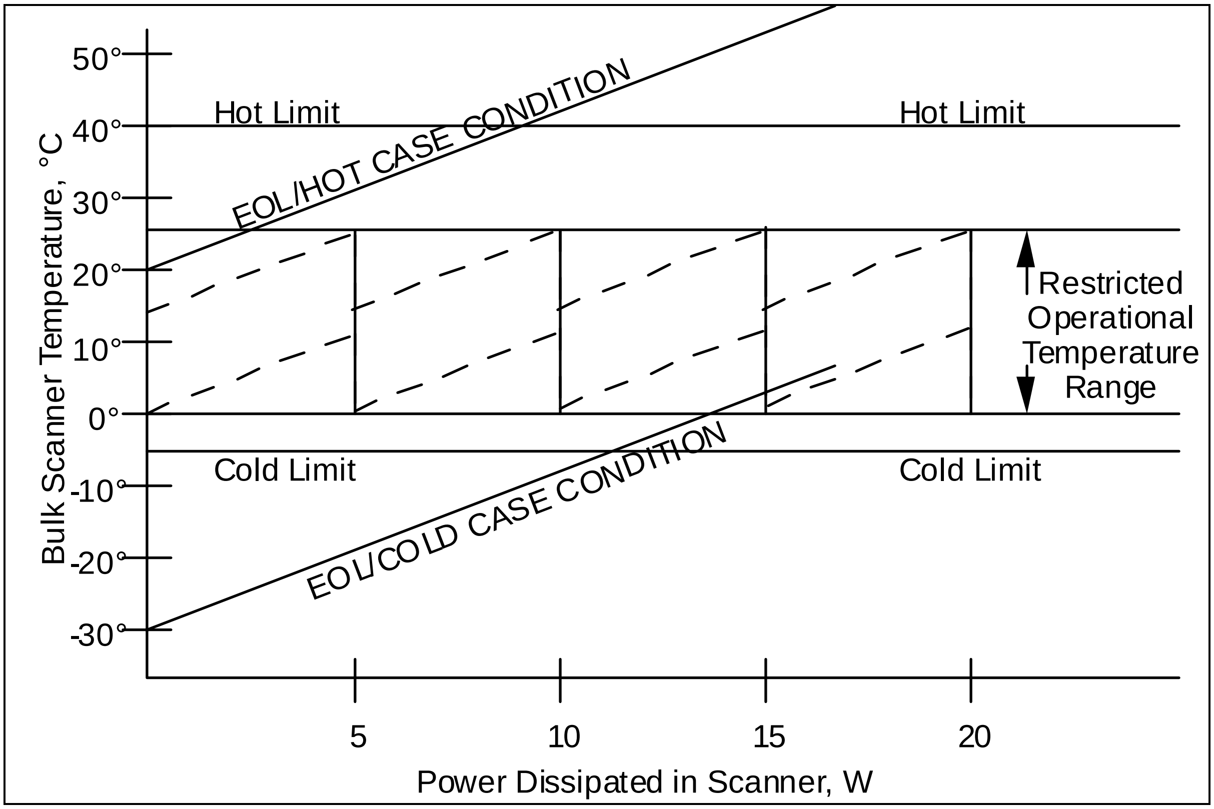

Figure 5.2-3 Thermal Monitoring

5.2.2 VIRS Special Operations

Operations for the VIRS instrument during instrument checkout will begin with a period of outgassing. Cooling of the VIRS detectors is provided by a passive radiative cooler. The Earth Shield door will be positioned slightly ajar during the outgas mode. VIRS will need to be passively outgassed for a couple weeks after initial deployment once TRMM has achieved its nominal mission orbit. VIRS instrument will remain OFF and all doors will be kept closed until this time. Plans to perform an active outgas for about 2-3 days after all contaminants are thought to have moved away will be coordinated with the Project and VIRS Instrument scientist. Outgas mode will be used for this active outgassing period. After initial outgas, there are no definite plans for additional outgassing. The need for outgassing the cooler is determined primarily by monitoring the Focal Plane Assembly (FPA) heater power telemetry. Less power required to maintain the FPA temperature setpoint is an indication that the cooler performance is degrading. At a certain threshold, outgas of the cooler or a change of the setpoint would be commanded. It is the intention to operate the VIRS at the 107K setpoint for the life of the mission, and only use the 117K setpoint if the cooler degrades significantly and cannot be recovered by outgassing. Outgas duration is approximately 3 days. Figure 5.2-4 depicts the cooler configuration in the Outgas mode.

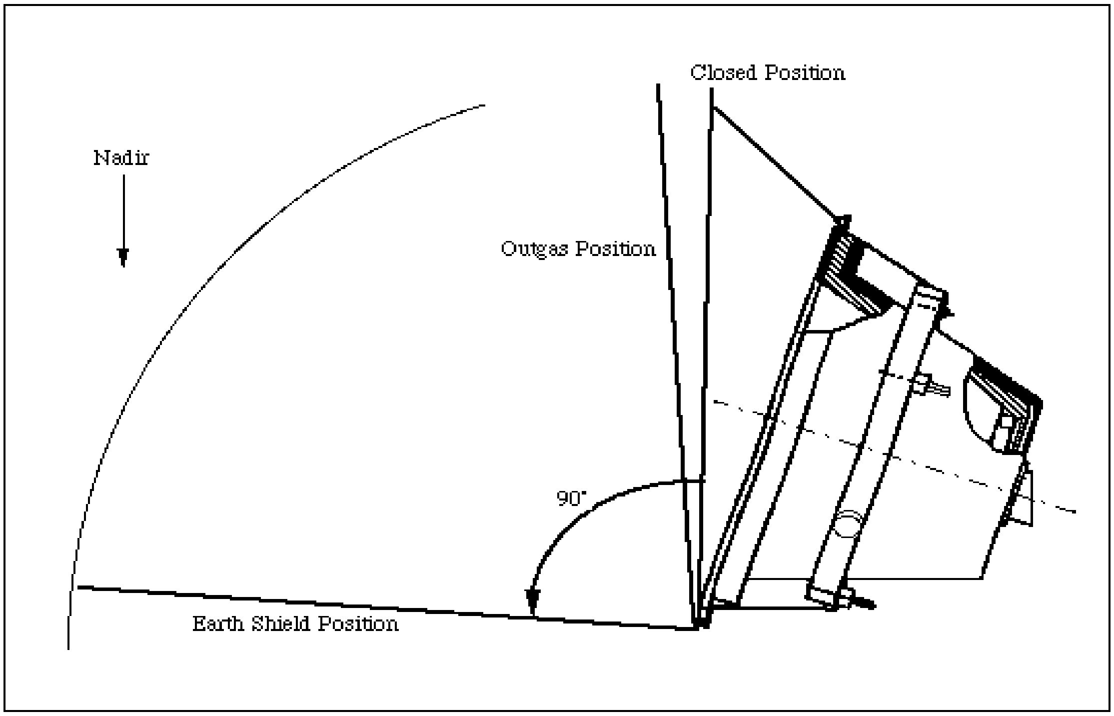

Figure 5.2-4 VIRS Outgassing Configuration

The contents of the VIRS microprocessor are not expected to be changed during normal mission operations. However, if an anomalous condition warrants a flight software change, a VIRS microprocessor patch load will be transferred to the MOC from the TSDIS SOCC. The MOC will convert this file to an uplink ready load.

Once an uplink ready load is received at the MOC, the FOT will send long commands to the instrument. VIRS memory loads can be uplinked with VIRS in any mode, and are performed by uplinking memory load command packets. The memory load command packets consist of the "Starting Address" of the uploaded data, the "Data's Length", and the "Load Data" itself. This is followed by a "CRC Validation Code" to ensure proper loading into the VIRS instrument.

The VIRS instrument will verify the uplinked CRC for each command received. Only commands passing this checksum verification will be loaded into memory. Afterwards, a Memory Dump should be performed via a Memory Dump command. Within this command a "Page Address", "Start Address", and "Length" will be issued to indicate the memory addresses to be dumped. Each dump command will generate a single dump packet of 1024 bytes. The dump data will be recorded on board the spacecraft, in place of science data. The recorded data will be played back during the next pass, and a Quicklook must be requested from the SDPF.

VIRS does not have any requirements for special configurations during spacecraft activities such as the Yaw maneuvers, Delta-V maneuvers, and the CERES Deep Space Calibration.

When a Safehold or Low Power condition occurs on the spacecraft, the IPSDU will issue a pulse, notifying the instruments that the Non-Essential bus power will be removed in 90 seconds. When VIRS receives this pulse, it will close the earth shield and solar calibrator doors and will obscure the radiative cooler optics with a shutter. The shutter will be energized using power from the Switched-Essential bus. Ninety seconds after receiving the pulse, the relay that provides Non-Essential bus power to the VIRS instrument will be commanded open and power will be removed from the instrument. Thermostatically controlled survival heaters will maintain survival temperatures on the instrument.

5.3 TRMM MICROWAVE IMAGER

The TMI is another instrument in the rain package. The TMI data combined with the data from the PR and VIRS will be used for deriving precipitation profiles. Based on the SSM/I heritage, the TMI is a multi-channel dual-polarized passive microwave radiometer. TMI utilizes nine channels with operating frequencies as shown in Table 5.3-1.

Channel #	Center *f* (GHz)	Bandwidth (MHz)	Polarity	Primary Purpose	Primary Data Area
1	10.65	100	Vertical	Very Heavy Rain	Ocean
2	10.65	100	Horizontal	Very Heavy Rain	Ocean
3	19.35	500	Vertical	Heavy Rain	Ocean
4	19.35	500	Horizontal	Heavy Rain	Ocean
5	21.3	200	Vertical	Water Vapor	Ocean
6	37.0	2000	Vertical	Light Rain	Land/ Ocean
7	37.0	2000	Horizontal	Light Rain	Land/ Ocean
8	85.5	3000	Vertical	Heavy Rain Light Rain	Land Ocean
9	85.5	3000	Horizontal	Heavy Rain Light Rain	Land Ocean

Table 5.3-1 TMI Channel Characteristics

TMI consists of a bucket/antenna assembly which constantly spins at a rate of 31.6 RPM. The spinning is controlled by the Bearing and Power Transfer Assembly (BAPTA), located inside the bucket assembly. The bucket /antenna assembly is supported by the baseplate, which is attached to the Upper Instrument Support Platform (UISP) on the +X side of the spacecraft. The antenna assembly consists of the main reflector and two non-spinning external load calibration assemblies. As the bucket/antenna assembly spins, the microwave signals from the Earth scene are reflected off of the main reflector and into the feed horns for measurements by the receivers. The feed horns and receivers are located inside the bucket assembly. Figure 5.3-1 shows the TMI instrument and its components. The momentum caused by the spinning of the instrument will be compensated for by the Attitude Control Subsystem.

Two feed horns are located in the instrument bucket. One horn is used for the two 10.65 GHz channels, while the other horn contains ports for the other 7 channels. The Signal Processing Unit (SPU), which consists of electronics also located inside the bucket, samples each channel at intervals as shown in Figure 5.3-2. The purpose of this timing control is to align the effective footprints of all channels in a correct cluster of positions for proper data combination.

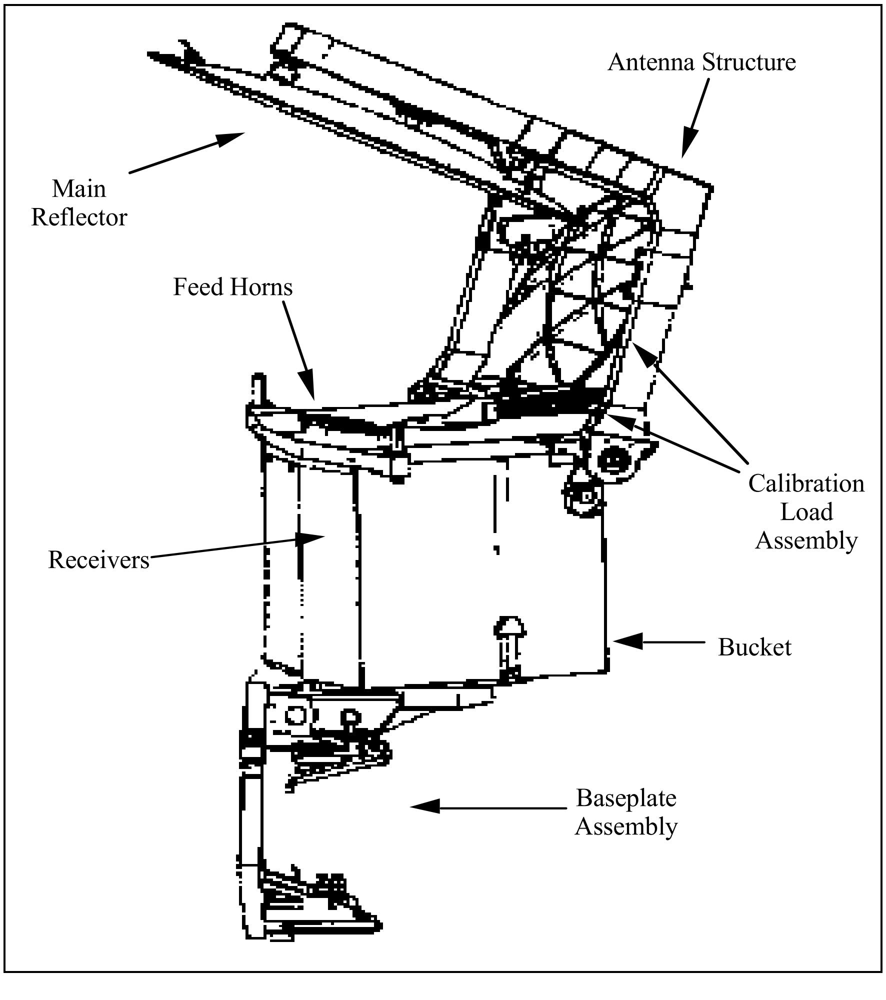

Figure 5.3-1 TRMM Microwave Imager

Two external calibrators on the BAPTA shaft are used to perform calibrations during each instrument rotation (scan). The calibrators will remain stationary as the main reflector and bucket assembly spin around it. Each scan will begin with 130° of scene data followed by a cold reference measurement, and then a warm load reference measurement. These reference measurements, along with the known temperatures of these calibration loads, serve to calibrate each scan.

The Signal Processing Unit (SPU) provides the interface of the instrument with the observatory. Control of the receivers and the spin cycle is accomplished though the SPU. TMI also possesses an Application Specific Integrated Circuit (ASIC) and Programmable Read Only Memory (PROM) which are located in the SPU. No on-orbit load/dump capabilities exist. The ASIC is a digital unit with off chip support of RAM and PROM which is used to control the data collection process. The SPU contains nine nearly identical circuit modules to process science data. Time tagging of the TMI housekeeping and science data is also a function of the SPU. The SPU provides Automatic Gain Control (AGC) on each of the receiver channels in order to compensate for the receiver gain variations. The SPU averages the hot load samples collected every scan for each channel for use in the AGC algorithm. The averaging is performed on only one channel at a time. Therefore, it takes 9 scans to perform one gain step adjustment on all nine channels.

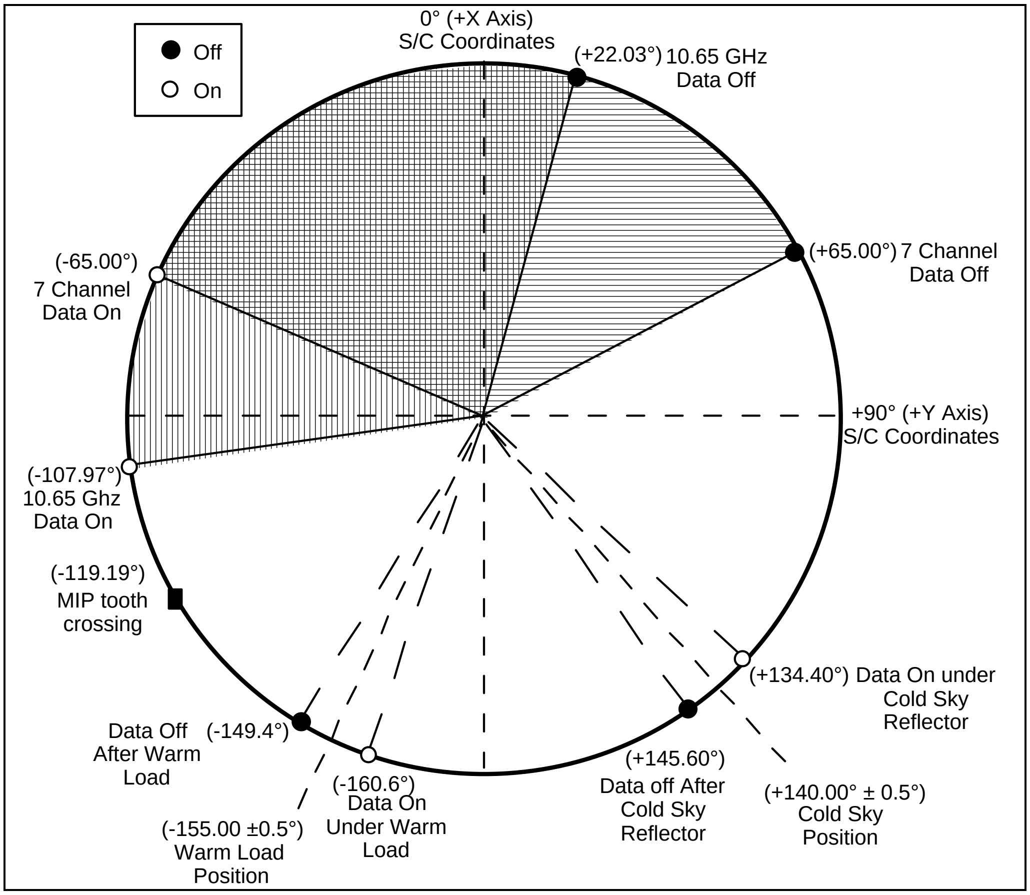

Figure 5.3-2 TMI Scan Profile

5.3.1 TMI Normal Operations

The TMI instrument has a single operational mode and no commandable redundancy. Accordingly, command procedures are minimal and will focus on power control. TMI essentially has two modes, OFF and ON. After initial power-up, it is intended that the TMI will remain powered at all times, barring any specific anomalies (i.e., Safehold, Low Power, TMI anomaly). In addition, no commanding is intended for the remainder of the mission. General health and safety monitoring of the TMI instrument during real-time events will be performed, and the SOCC will be notified of any anomalous behavior.

5.3.2 TMI Special Operations

No special TMI activities will be necessary during Delta-V, Yaw, or Deep Space Calibration maneuvers. In addition, TMI will not receive the Safehold/Low power pulse since it has no special requirements for the shutdown of the instrument. Therefore, power will be removed from the instrument without any notification.

5.4 CLOUDS AND EARTH'S RADIANT ENERGY SYSTEM

The CERES instrument is located nadir on the -X end of the TRMM observatory and is physically connected to the LISP, as shown in Figure 5-1. The CERES instrument draws on the ERBE heritage, both in design and in the way the instrument will be operated in flight. In addition, the CERES instrument design includes the following features: higher sample rate and increased measurement resolution, Biaxial scan capability, bi-directional elevation scan, re-programmable computers, and a solar avoidance system. Figure 5.4-1 shows the CERES instrument and its components.

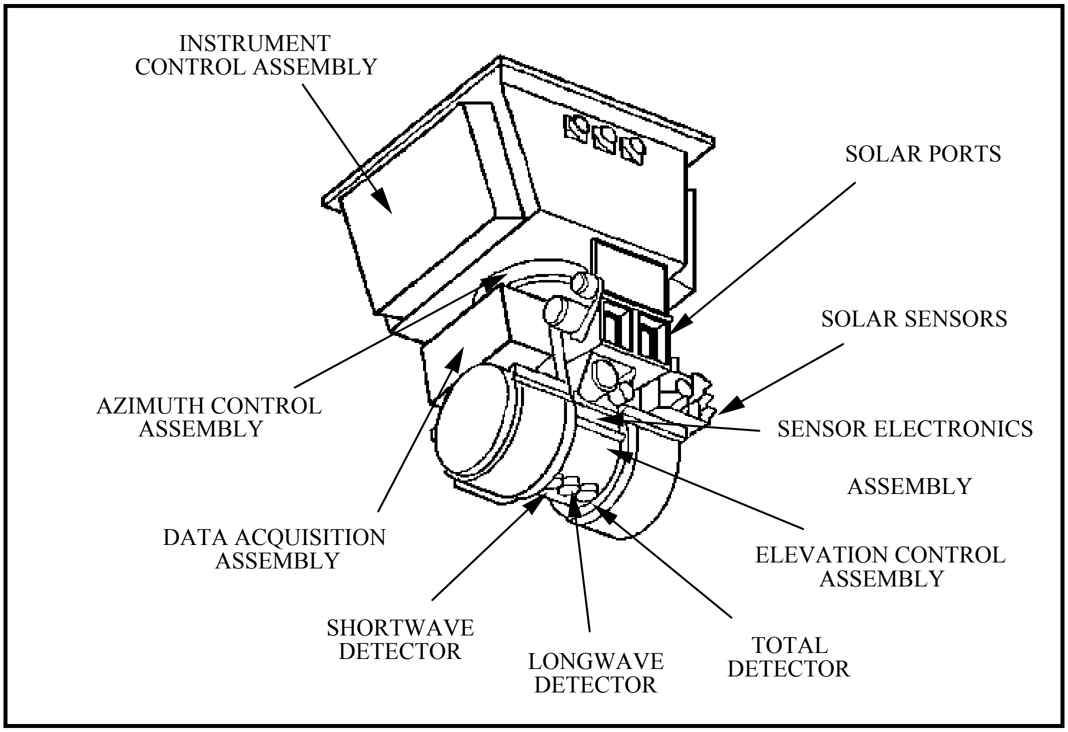

Figure 5.4-1 Clouds and Earth's Radiant Energy System Instrument

The radiometer sensor system consists of three co-aligned broad band thermistor bolometer detectors which sample the Earth's radiation in three spectral ranges (total, longwave, and shortwave). The three detectors are identical except for optical filters on two detectors (longwave and shortwave) which restrict their spectral ranges to a portion of the Earth's radiation bandwidth. Output of the three detectors are sampled simultaneously 100 times per second.

The detectors can scan simultaneously about two orthogonal axes. The azimuth control assembly can rotate to any angle between 0° and 350° or it can rotate back and forth continuously between two specified azimuth angles. The elevation control assembly can rotate the detectors in a range between 11° and 260°. Elevation scan profiles include three Earth scan profiles, a solar calibration profile, and a scan-to-stow profile. Included in the Earth scan profiles are normal, short, and nadir profiles. Table 5.4-1 lists the nine operational modes of the CERES instrument, together with pertinent information, or distinguishing features, about how the instrument is normally configured for operation within each mode. figure 5.4-2 illustrates some elevation scan positions of the CERES instrument pertinent to operation at the altitude of the TRMM spacecraft.

Mode	Nominal Profile	Secondary Profile	Azimuth Angle	APID
Crosstrack	Normal Earth Scan	N/A	Crosstrack (180°)	Science
Biaxial	Normal Earth Scan	Short Scan	Uprange-Downrange (90°-270°), (110°-250°)	Science
Solar Calibration	MAM Scan	N/A	At Predicted Sun Angle	Calibration
Hold	Scan Head Stowed	N/A	At arbitrary angle, brake released	Diagnostic
Standby	Scan Head Stowed	N/A	At arbitrary angle*	Diagnostic
Contamination Safe	Scan Head Stowed	N/A	Contamsafe Position, TBD°	Diagnostic
Diagnostic	Scan Head Stowed	N/A	Initially braked at arbitrary angle	Diagnostic
Safe	Scan Head Stowed	N/A	Braked at arbitrary angle	Diagnostic
Survival	Scan Head Stowed	N/A	Braked at arbitrary angle	None

*Initially braked if entering from Safe mode.

Table 5.4-1 CERES Operational Modes

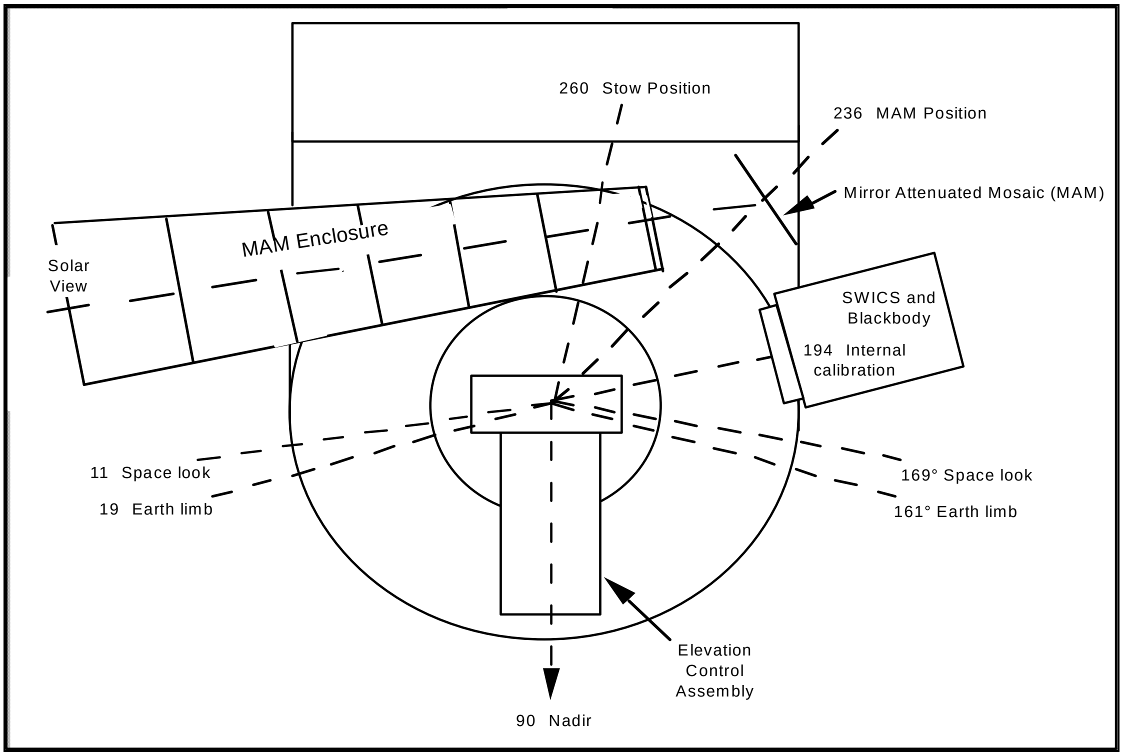

Figure 5.4-2 CERES Scan Positions

The instrument includes two kinds of internal calibration sources. Two blackbodies are used to calibrate the long and total wavelength detectors, and a Short Wave Internal Calibration Source (SWICS) is used to check the stability of the shortwave detector. The detectors can also be calibrated using the attenuated output of the Sun.

Two assemblies provide control and direction of instrument operations and data output via stored or real-time commands. Each assembly contains a dedicated SQ 80C186 microprocessor which may be programmed in flight to restore command tables and to add new internal command sequences. However, reprogramming the instrument microprocessors is thought to occur very infrequently, barring any anomalous behavior. Most of the CERES commanding activity will be implemented via preprogrammed internally stored command sequences.

A solar avoidance system is provided to prevent damage to the detectors by exposure to direct sunlight. The primary solar avoidance system includes command-control capability to switch to a special Sun-avoidance scan profile during high-risk periods of Sun exposure (i.e., short scan capability). The secondary method consists of a time-out command which will place CERES into the short scan profile while operating in the Biaxial mode if the number of normal scans reaches a previously calculated value. The backup solar avoidance system includes Sun Presence Sensors (SPS) which will take action to stow the detectors if there is a threat of viewing the Sun.

5.4.1 CERES Normal Operations

CERES instrument commanding will be more frequent than any of the other instruments. The majority of instrument commands will be issued from the spacecraft SCP. During normal science operations, the instrument will operate in the Crosstrack and the Biaxial Scan modes, 66% and 33% of the time, respectively. Operations in these two science gathering modes will be interrupted periodically (every 2 weeks) to allow the instrument to perform solar and internal calibrations. Internal calibrations are performed while the instrument is operating in either the Crosstrack or Biaxial Scan modes while performing a normal Earth scan profile.

CERES will be placed into Crosstrack mode via stored command which will initiate execution of an internal sequence. When in Crosstrack mode, the instrument will rotate only in elevation from horizon to horizon, while being kept stationary at a fixed azimuth angle of 180°. No input parameters are normally required for commands which change operation to the Crosstrack mode. There are no orbit-parameter constraints for operation in this mode, and there are no Sun avoidance commands required while in the Crosstrack mode. The baseline command sequence causes the instrument to execute the normal Earth scan profile continuously at a fixed azimuth angle.

While operating in the Biaxial scan mode, the azimuth gimbal will rotate back and forth (normally between 90° and 270°) while the elevation gimbal performs either a normal or short Earth scan profile. Stored commands switch instrument operation between the normal and short Earth scan profiles around sunrise and sunset to prevent the detectors from directly scanning the Sun. In addition, a command will be sent prior to each normal scan command to trigger a count of the scans during the normal scan profile. If the number of scans reaches the number specified as the argument in the command, CERES will be autonomously commanded to the short scan profile. The times of the commands are based on predictive Sun elevation data.

The normal azimuth gimbal rotation range of 90° to 270° will be in effect when values of the beta angle are less than -20° or greater than +20°. When values of the beta angle are in the range between -20° and +20°, the azimuth gimbal will be restricted to rotate in a range between 110° and 250°. The switch in instrument operation between the two azimuth rotation ranges is performed via stored commands, whose times of execution are based on predicted values of beta angle. The restricted azimuth rotation range (110° to 250°) is necessary to prevent the detectors from scanning closer than 20° to the Sun during sunrise and sunset.

CERES calibrations will be performed every two weeks. The elevation of the Sun during Solar calibrations will be -11° and the azimuth of the instrument will be set to correspond with the elevation angle so that the Sun is in the field of view of the MAM. Solar calibrations will be performed according to the preprogrammed sequence in the instrument's microprocessor. Prior to beginning the solar calibration, the predicted value of the solar calibration azimuth angle will be uploaded and executed via an instrument data command. This command can be uplinked and time-tagged for execution anytime before initiation of the solar calibration sequence. The baseline plan calls for commanding the instrument to Standby mode and then executing the calibration. The sequence will last about 30 minutes and will return the instrument to the Standby mode upon completion.

An internal calibration will normally be performed immediately after completion of a solar calibration. The internal calibration sequence turns the internal calibration sources on and off in a preprogrammed sequence. Calibration data are acquired while the elevation gimbal performs a normal Earth scan profile and the instrument is operating in either the Crosstrack or Biaxial scan mode.

Each daily command load will include commands to safe the instrument (a safing sequence) in the event that the next days commands are not uplinked. Switching between two operational modes will normally require only one absolute time-tagged stored command to be loaded in the spacecraft SCP. This command will initiate the execution of a pre-programmed command sequence located in instrument memory to configure CERES for operation in the new mode. Additionally, normal CERES operations will include routine health and safety monitoring, configuration verification, and mode commanding performed by the FOT.

5.4.2 CERES Special Operations

A Deep Space Calibration will be performed during the instrument checkout period. To perform this calibration, the CERES instrument will require that the TRMM spacecraft attitude be modified from nadir pointing to an inertially fixed attitude. This will be performed when the Beta angle is between 15 and 23 degrees or between -15 and -23 degrees. LaRC has requested that CERES perform 6 orbits of Deep Space Calibrations. However, it is required by the TRMM Project that orbits in the inertially fixed attitude be non-contiguous. The 6 orbits for the Deep Space Calibration will be performed over a 24 - 48 hour time frame. The entry into the inertially fixed attitude configuration must occur at orbit noon to place the +Z axis (normal nadir pointing) of the spacecraft away from the Sun. This will permit the CERES instrument to scan space over the full conical field-of-view during the night portion of the orbit. There is no preference for orientation of the X-axis for the spacecraft (X axis forward or backward) for the initial Deep Space Calibration. Figure 5.4-3 illustrates the Earth-Sun-spacecraft configuration during one orbit of the Deep Space Calibration inertial hold attitude. This configuration will permit the CERES instrument to make measurements while viewing space and operating in the two normal science modes (Crosstrack and Biaxial). The CERES instrument detectors will have unobstructed views of space during the entire night portion of the orbit when the instrument is operating in the Crosstrack scan mode. Furthermore, the detectors will have unobstructed views of space at all viewing positions during a portion of the orbit centered at orbit midnight when the instrument is operating in the Biaxial scan mode. The CERES scientists may request an additional Deep Space Calibration during the TRMM mission. This request will be considered by the MD and the TRMM Joint Science Team for effects on the other instruments and the spacecraft.

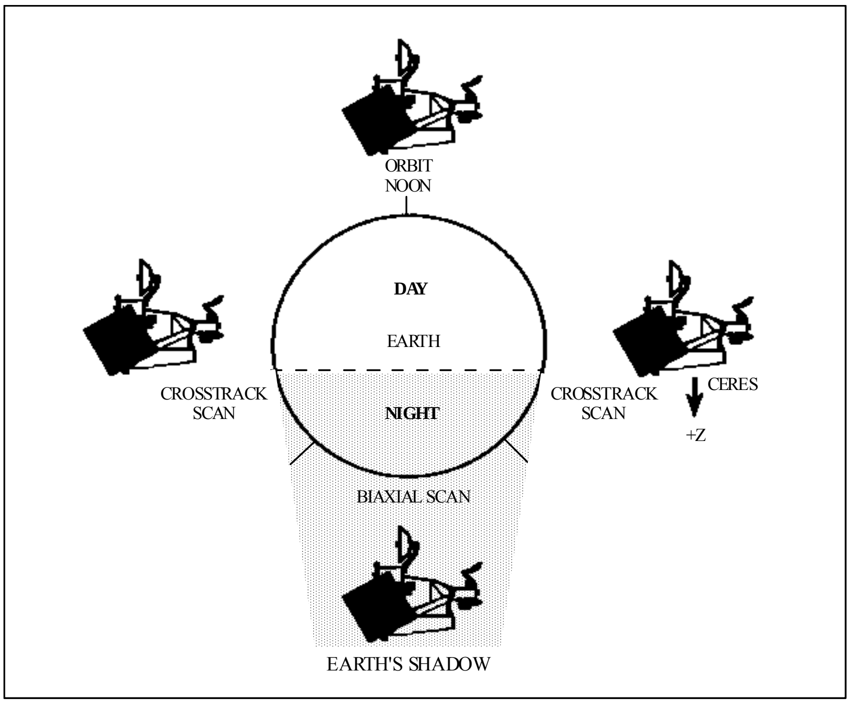

Figure 5.4-3 CERES Deep Space Calibration Configuration

Every 2 to 4 weeks, whenever the spacecraft performs a 180° yaw maneuver, CERES will be commanded to the Contamination Safe mode, with the scan head stowed, until attitude control is settled after the maneuver. CERES will also be placed in the Contamination Safe mode during the PR antenna pattern measurement, when a 90° yaw is required. Again, CERES will be placed back in normal mode after a brief settling period. The CERES instrument will be placed in Contamination Safe mode before a Delta-V maneuver is performed. CERES will be placed into the Contamination Safe mode during each of the 2 burns, but will continue to operate normally between the 2 burns, and after the second burn. While in the Contamination Safe mode, Sun avoidance commands which are already present in the SCP will be not be permitted to execute by CERES.

CERES microprocessor operations will fall under the direction of the LaRC representatives. The microprocessors will execute the programs loaded in memory to perform the scientific observations required. FOT operations will involve verifying program checksum of the microprocessors memory and the execution of instrument state verification procedures which would also verify proper microprocessor execution. Situations may arise where the FOT will have to perform other operations not considered nominal for the FOT (i.e., uplink a patch or new microprocessor load, dump the microprocessor contents, etc...). No microprocessor or instrument operations will be performed by the FOT without direction from the LaRC instrument representative. LaRC, as well as the FOT, shall monitor instrument microprocessor activities, to verify proper operations. Table 5.4-2 lists the CERES microprocessors and their characteristics. The table also shows the amount of time required to dump each portion of memory. Note that memory of both microprocessors are dumped simultaneously, so that the total amount of time required to dump available RAM and ROM at a dump rate of 1.6 Kbps for both microprocessors are 640 and 240 seconds, respectively, as noted in the table.

Characteristics	Instrument Control Processor (ICP)	Data Acquisition Processor (DAP)
RAM (KBytes)	128.0	128.0
Used RAM (KBytes)	18.4	13.1
Memory Dump Rate* (bits/sec)	1.6	1.6
Time to Dump RAM (sec)**	640	640
Time to Dump ROM (sec)**	240	240

*1.6 bits/sec data rate is only a portion of the total 9 Kbps data rate allocated to CERES
**Time to Dump RAM and ROM is based on dumping entire RAM and ROM

Table 5.4-2 CERES Microprocessors

If a microprocessor load is required for CERES, LaRC will electronically send the required load (in an agreed upon format) to the MOC, via the existing interface (planning aids, reports, remote displays, etc...). The MOC will receive this file, and convert it to an uplink ready load for the FOT. By design, microprocessor loads can be uplinked to the spacecraft while the instrument is in any operational mode while all other types of long commands can only be executed from the Diagnostic mode. Baseline operations, however, will be performed as follows. Once the load is ready it will be uplinked to the spacecraft during a previously agreed upon real-time support . Prior to loading the microprocessor, the CERES instrument will be commanded to the Safe mode. From the Safe mode, a real-time command will be issued to command CERES into the Diagnostic Mode. (Note: When in the Diagnostic mode, all CERES stored commands will still execute if commanded in the ATS load. Therefore, caution should be taken to avoid executing any CERES stored commands while in the Diagnostic mode). The load will then be uplinked to the spacecraft. (Note: At a 1000 bps command rate, it would require approximately 17 minutes to load the entire RAM of 1 processor).

Following successful completion of a load, the microprocessor will be dumped. Microprocessor dumps may also be requested for trouble shooting purposes. Memory dump data are produced in place of science data while in the Diagnostic mode, and are recorded onboard. CERES memory dumps are not downlinked in real-time.

After the dump is complete, the instrument will be commanded to the Safe Mode, via a real-time command, until further direction from LaRC. Another real-time command will be required to exit Safe mode. During the next TDRS support, the contents of the solid state recorder will be downlinked. This playback data will include the CERES microprocessor dump data. A Quicklook containing the CERES microprocessor dump data will be requested for transfer to LaRC. LaRC will be responsible for successful microprocessor load/dump verification.

The above approach is the current baseline, since operationally, microprocessor loads will not be routine. However, if during the TRMM mission, routine loading is required, an alternative approach may be considered. The alternative approach differs only slightly, in that a memory dump would not be required. Instead, along with the microprocessor load, LaRC will provide a checksum (computed for the new memory contents). Normally, CERES computes a checksum of its memory, and downlinks this computation in the CERES housekeeping packet. The FOT would compare the LaRC computed checksum, with the CERES computed checksum (downlinked in the housekeeping packet). If a successful comparison occurred, CERES would be commanded back to a normal operations mode (i.e., Diagnostic; to Safe; to Standby; to Normal operations), and no dump would be required.

When a Safehold or Low Power condition occurs on the spacecraft, the IPSDU will issue a pulse, notifying the instruments that the Non-Essential Bus power will be removed in 90 seconds. When CERES receives this pulse, it will issue a scan to stow command which will stow the detectors at the 260° stow position. This will take no more than 2 scan cycles (of a total of 13.2 seconds). Ninety seconds after receiving the pulse, the relay that provides Non-Essential bus power to the CERES instrument will be commanded open and power will be removed from the instrument. Once power has been restored to CERES, a microprocessor load will be necessary to load any tables that had been loaded since the previous removal of power.

5.5 LIGHTNING IMAGING SENSOR

The LIS instrument is located nadir on the -X end of the TRMM observatory and is physically connected to the LISP as shown in Figure 5-1. LIS is comprised of the Sensor Head Assembly and the Electronics Assembly as shown in Figure 5.5-1. The next paragraphs will describe the two main components of the LIS instrument. The instrument senses the lightning flashes and reports the time, location, and amplitude of the optical emissions from each lightning. The cloud background scene is also recorded.

The Sensor Head Assembly consists of a lens/filter subsystem and a focal plane subsystem. The sensor continuously stares towards the Earth and waits for a flash of lightning. When a flash is sensed, the lightning is imaged by the Charged Coupled Device (CCD). The time of the occurrence is determined to within two milliseconds. The event data are processed in the Electronics Assembly.

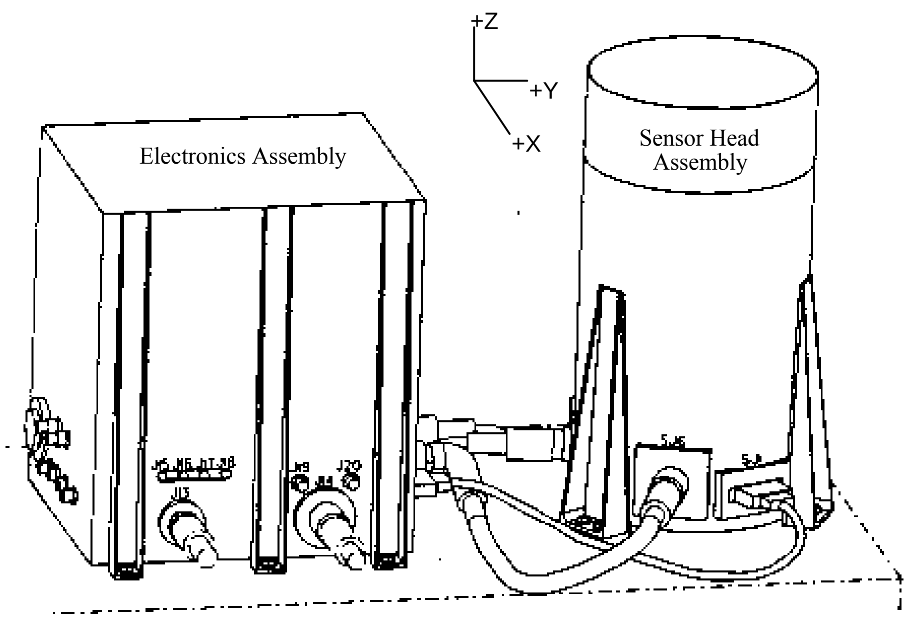

Figure 5.5-1 Lightning Imaging Sensor

The Electronics Assembly contains the Real-Time Event Processor (RTEP) boards which perform the discrimination of the lightning against the background scene, the Controller board which performs the calculation of event location and amplitude, and the Interface board which performs housekeeping and data formatting. The RTEP is not reprogrammable on orbit. Table 5.5-1 describes additional characteristics of the LIS instrument.

CRITERIA	SPECIFICATION
Instantaneous FOV	590 X 590 km
Square FOV	80° X 80°
Spatial Resolution	≤ 4 km
Wavelength	777.4 nm
Temporal Resolution	2 ms
CCD specification	128 X 128 pixel

Table 5.5-1 LIS Instrument Specifications

5.5.1 LIS Normal Operations

During normal science operations, the LIS instrument will continuously operate through day and night in the science mode. The instrument will acquire successive observations every 2 ms. If a lightning event is identified during this 2 ms sample period, then the location, intensity, and time of each event is reported. In addition to the lightning events, background scene is also transmitted to maintain a constant data rate.

Only limited instrument command activity will be needed during the spacecraft mission mode. Normal operations will consist of instrument health and safety monitoring. Once powered, the LIS instrument will be configured for a normal science data collection mode. The FOT, during normal operations, need only to verify this configuration. In addition, continuous automated limit checking will be performed during all real-time contacts with the spacecraft.

Instrument commanding will be more frequent during L&IOC until instrument checkout has been completed. Operations will almost exclusively consist of changing the threshold values in the RTEP. Once data is analyzed, and the best threshold values are determined, commanding will be minimal.

5.5.2 LIS Special Operations

LIS does not have any requirements for special configurations during spacecraft activities such as the Yaw maneuvers, Delta-V maneuvers, or the CERES Deep Space Calibration.

The LIS instrument does not receive the Safehold/Low Power pulse in the instance of a spacecraft problem. LIS does not require any time to power itself down. Therefore, power is removed from the instrument without any notification.

5.6 Instrument Activities

Some instrument configurations depend on other instrument and spacecraft activities. The correlation between activities and instrument mode resulting from that activity is shown in Table 5.6-1.

Activity	Activity Duration	Settling Time	Frequency	PR Mode	VIRS Mode	TMI Mode	CERES Mode	LIS Mode
180° Yaw (Thermal & Power)	17 minutes	included in activity duration	every 2 to 4 weeks	Normal	Normal	Normal	Contam Safe	Normal
Delta-V (Orbit Attitude Maintenance)	two 50 sec burns spaced by 45 minutes	about 5 minutes	every 7-10 days BOL, Every other day middle of life	Normal	Normal	Normal	Contam Safe	Normal
90° Yaw (PR Antenna Pattern Measurement)	35 minutes	included in activity duration	every 6 months	External Cal	Normal	Normal	Contam Safe	Normal
CERES Deep Space Calibration	6 orbits (non-contiguous within 48 hours)	about 3 minutes	once early orbit checkout	Standby	Normal	Normal	Normal	Normal

Table 5.6-1 Instrument Configuration vs. Activity